

## OVERVIEW OF NASA BATTERY TECHNOLOGY PROGRAM

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I am going to be highlighting OAST's technology program in batteries for space applications. I will be presenting highlights only, not only because of the time constraints, but also because many subsequent speakers will be presenting details of the program elements, and because there will be an article in the special January issue of the "Advanced Battery Technology Newsletter," which will discuss the mass of OAST battery technology programs in greater detail.

The electrochemistry program in OAST includes not only batteries but also fuel cells and electrolysis technology. Because this is a battery workshop, I am going to be restricting my remarks today only to the battery portion of the program.

And finally, I will be discussing only the technology work that we are sponsoring. The flight experience will be discussed on Wednesday.

The OAST battery technology program is funded at roughly \$2 million a year, and in FY 80 that level of funding will be continued. Of that amount, approximately two-thirds is managed and spent by the Lewis Research Center in Cleveland; and one-third, by the Jet Propulsion Laboratory in Pasadena, California. Of that same total of \$2 million, approximately one-half is in-house work, and the remaining half is contracting with industry and is awarded as grants to universities.

(Figure 1-1)

This vugraph indicates some of the program elements or what is in the program. First, we have advanced ambient temperature alkaline secondaries, which are primarily nickel-cadmium cells in batteries.

Then, we have secondaries with multi-kilowatt-hour storage capacity primarily for lower orbital applications that we see in the future. Those are mainly toroidal nickel cadmium, and there is a fuel cell electrolyzer program going on at the Johnson Space Center. But, since that is not a battery program, it will not be discussed today.

The program also includes ambient temperature lithium batteries, both primary and secondary, high-energy density, higher than ambient temperature secondaries. Finally, metal-gas secondaries, primarily silver hydrogen, and high-capacity nickel hydrogen are included in the program.

(Figure 1-2)

The general objectives of all these elements of the technology program are to increase the useful energy density; to increase the storage capacity, primarily for lower orbital applications; to

extend the useful life; to extend the cycle capability for secondaries, of course; and to always improve the reliability and the safety of these devices.

(Figure 1-3)

This chart summarizes some of our near-term specific objectives. In the interests of time, I am not going to cover every cell in this matrix, but this chart will be in the proceedings.

By the near term we mean the mid-1980s for the most part. By 1983 to 1985, we would hope to have brought the technology along to the state where electrochemical systems would have these particular characteristics for our applications.

The first column on this chart indicates what those applications are. As you can see, it spans the spectrum of all the regions of space in which we are interested from low-Earth orbit all the way out to geosynchronous planetary orbiters, landers, and probes. Each of those has its own special requirements in terms of capacity and energy density.

The second column indicates the major electrochemical system which is being advanced for those applications. You can see that we have some nickel-cadmium work going on, as well as some silver hydrogen sodium chalcogenide and several lithium systems.

Among these specific objectives, with the exception of the low-Earth orbiters where our major objective is the 100-ampere hour capacity, the primary near-term objective for all of the other application systems are the cell energy density and the battery life. The numbers in those columns represent our near-term objectives.

For completion, we have indicated cycle life and corresponding depth of discharge to add some meaning to those numbers.

(Figure 1-4)

In the remainder of my presentation, I want to cover just some of the highlights of these different program elements. In advanced alkaline secondaries, two primary objectives are to develop a fundamental understanding of nickel cadmium, cell degradation, and failure mechanisms and to embody these in some kind of a useful, reliable, predictive model that users can actually employ.

Also, we would like to achieve longer life, i.e., greater than 900 or 1000 cycles, greater than 10 years, and get the specific energy up greater than 26 watt-hours per kilogram with the nickel-cadmium system.

An approach to this is improvements in separator technology, technology of electrodes, and reconditioning procedures. Most of that you will hear about subsequently.

There has been a good deal of progress going on in this entire program, but in limited time, it is very difficult to convey all of that progress. Fortunately, a number of the speakers who will follow me over the next several days will be highlighting their progress in a lot more detail.

Recent progress in nickel cadmium, however, includes the attainment of superior hydrogen recombination rates under reversal conditions. It has been demonstrated by Lewis, PRW, in C/2 discharge rates and some new experimental cell design, which I understand will be discussed on Wednesday.

Also, a failure model for nickel-cadmium cells has been developed and partially validated at JPL, and that will be discussed on Thursday.

(Figure 1-5)

The objective of multi-kilowatt-hour storage technology is to establish the feasibility of a greater than 100-ampere hour, greater than 5-year life, and relatively low-cost nickel-cadmium cell of a toroidal configuration relatively soon, by the end of this fiscal year. Then, depending on how feasible it looks, further development may be undertaken.

Also, NASA/OAST is interested in a preliminary evaluation of nickel-hydrogen batteries somewhere in the range of 65 watt-hours per kilogram for high capacity, lower orbit applications. While most of that work is being conducted by the Air Force for tracking, there is a small in-house program going on at Lewis to take a closer look at that technology for our applications.

Recent progress in this area includes the design of a toroidal cell and investigation of fabrication, and sealing techniques have been initiated by Lewis.

(Figure 1-6)

Lithium systems—Work is going on both in primaries and secondaries. One objective is to demonstrate a safe 300 or more watt-hour per kilogram primary battery for probe applications with a 5-year storage life at relatively high drain conditions by the end of FY 84.

Another objective is to demonstrate a 220-watt-hour per kilogram secondary battery for lander applications by the end of FY 82. It may turn out that a target of 150 watt-hours per kilogram might be more reasonable. That is under consideration.

The approach in the lithium program is, first of all, to gain a fundamental understanding of the physical and chemical processes which are unique to lithium-based systems; also, to develop and characterize new or improved electrodes, electrolytes, and materials; and third, to develop a NASA in-house capability to fabricate prototype cells and to write design specifications.

In the past, NASA's lithium technology program has been, in my estimation, overly beholden to contractors and their capabilities. We now feel NASA would benefit from having a stronger in-house capability in lithium systems. Consequently, the lithium program has been reoriented along those lines within the past 6 months.

Recently, lithium anode conducting film modeling has been going on at JPL. Lithium hexafluoroarsenate has been selected as a primary candidate electrolyte for study in secondary cells. These will be discussed in more detail by several speakers this afternoon.

(Figure 1-7)

In the high energy density secondary systems, we have an objective of establishing the feasibility of 5-year again graded in 200 watt-hour per kilogram energy density secondary batteries by the end of FY 82. This work is being carried out at the Lewis Research Center. The approach centers about the use of liquid sodium anodes, thin beta alumina solid electrolytes, and solid transition metal, chalcogenides for reversible intercalation of sodium ions.

Recent progress has been a demonstration of the feasibility irreversibly intercalating up to two equivalents of sodium ion in vanadium disulfide and  $\text{NiPS}_3$  at high temperatures.

(Figure 1-8)

Finally, in the metal gas secondaries, we want to complete both our preliminary evaluation of a 77-watt-hour per kilogram 50-ampere hour silver hydrogen cell this fiscal year and that evaluation of nickel-hydrogen batteries which I discussed earlier. This subject overlaps that of the multi-kilowatt-hour energy storage program element.

Recent progress at the Lewis Research Center includes demonstration of a 50-ampere hour 80-watt-hour per kilogram silver hydrogen cell which has completed 600 cycles. Also, in more basic research at that center, certain silver electrodes have demonstrated 1500 cycles in single cell tests.

Before concluding, I should point out that NASA is also advancing the technology of secondary nickel-zinc systems for terrestrial applications under its technology utilization program. This is work which is not directly sponsored by OAST. NASA is also responsible for several electrochemical technology programs or projects which are being carried out for the Department of Energy.

These generally center about batteries for electric and hybrid vehicles and energy storage for utility power generation. But our emphasis, or at least the emphasis in my presentation, has been on space technology, so I won't discuss those any further here.

## DISCUSSION

LEAR: I would like to ask you about the silver hydrogen tests that were conducted at NASA Lewis. What sort of criteria were you testing with the silver hydrogen cells?

RIEBLING: I regret I cannot give you very many details of that, but there is a representative from Lewis in the audience. I would like him to identify himself and hopefully respond to that question.

SMITHRICK: The question that was asked on the silver hydrogen cycle life data, as I remember it, was what were the specific test conditions for the cycle life?

Well, it was an accelerated synchronous orbit test, an 8-hour cycle, consisting of 6.8 hours of charge and 1.2 hours of discharge. The discharge and charge were both at constant currents, and

the depth of discharge was 75 percent. If the voltage should drop below 0.9 volt, that is defined as the end of life.

The data presented was for a 50-ampere hour cell. There is also some data for a 35-ampere hour cell. The 35-ampere hour cell was cycled for over 960 cycles, and the test is still being continued.

LEAR: What was the constant current rate that you had during the charge and the discharge?

SMITHRICK: The cell that was presented was a 50-ampere hour cell. So, the current is 50-ampere hours divided by 1.2 hours, whatever that number comes out to. You know for a 75-percent depth of discharge, I don't have a calculator with me, but that is the way we figure it out. Of course, the same thing would be for the charge.

You take 50-ampere hours and multiply it by 0.75 and that comes out to—well, whatever it comes out to, and just divide that.

RIEBLING: I should say that the silver hydrogen work is not a large or major element of our technology program. This work is nearly complete and is being phased out. The primary reason is that the metal gas cells are being developed by other agencies, and probably the nickel-hydrogen systems are the ones that will likely find themselves in use in the near term, so the silver hydrogen is being relinquished to the back burner for a while.

## PROGRAM ELEMENTS

- ADVANCED AMBIENT-TEMPERATURE ALKALINE SECONDARIES
- MULTI-KWH CAPACITY SECONDARIES
- AMBIENT-TEMPERATURE LITHIUM PRIMARIES AND SECONDARIES
- HIGH-ENERGY-DENSITY, ABOVE AMBIENT TEMPERATURE SECONDARIES
- METAL-GAS SECONDARIES

Figure 1-1

## NEAR-TERM SPECIFIC OBJECTIVES

PRIMARY APPLICATION	ELECTROCHEMICAL SYSTEM	CAPACITY Ah	CELL ENERGY DENSITY, Wh/kg	BATTERY LIFE, YR	CYCLE LIFE	DOD %
LOW EARTH ORBITERS	Ni-Cd (TORROIDAL)	100	30	5	25,000	20
GEOSYNCHRONOUS ORBITERS	Ag-H <sub>2</sub>	50	66	10	1,000	75
	Na/CHALCOGENIDE	100	300	5-10	1,000	75
PLANETARY ORBITERS	Li-TiS <sub>2</sub>	5-10	220	10	500	65
PLANETARY LANDERS	Li-TiS <sub>2</sub>	5-10	220	10	5,000	35
PLANETARY PROBES	LiSOCL <sub>2</sub>	20-50	330	5	PRIMARY	80

Figure 1-3

## GENERAL OBJECTIVES

ADVANCE PRIMARY AND SECONDARY SPACE BATTERY TECHNOLOGY TO INCREASE:

- ENERGY DENSITY
- STORAGE CAPACITY (LEO)
- USEFUL LIFE
- CYCLE CAPABILITY (SECONDARIES)
- RELIABILITY AND SAFETY

Figure 1-2

## ADVANCED ALKALINE SECONDARIES

## POTENTIAL APPLICATIONS

- GEOSYNCHRONOUS ORBITERS
- NEAR-TERM PLANETARY ORBITERS

## OBJECTIVES

- DEVELOP FUNDAMENTAL UNDERSTANDING OF NiCd CELL DEGRADATION AND FAILURE MECHANISMS, EMBODY IN PREDICTIVE MODEL
- ACHIEVE LONG LIFE (>900 CYCLES, >10 YR) AND HIGH SPECIFIC ENERGY (>26 Whr/kg) WITH NiCd BATTERIES THROUGH IMPROVEMENTS IN SEPARATORS, ELECTRODES, AND RECONDITIONING PROCEDURES

## RECENT PROGRESS

- SUPERIOR H<sub>2</sub> RECOMBINATION AT  $\pm 40V$ , DEMONSTRATED BY LeRC/TRW AT C/2 OVERDISCHARGE RATES IN NEW EXPERIMENTAL CELL DESIGNS
- FAILURE MODEL FOR NiCd CELLS DEVELOPED AND PARTIALLY VALIDATED AT JPL

Figure 1-4

POTENTIAL APPLICATIONS

- LOW-EARTH ORBITERS

OBJECTIVES

- DETERMINE FEASIBILITY OF  $>100$  A-HR,  $>5$ -YR LIFE,  $< \$30$ /W-HR TORROIDAL  $\text{NiCd}$  CELL BY EOFY'80
- COMPLETE PRELIMINARY EVALUATION OF  $\text{Ni-H}_2$  BATTERIES FOR HIGH-CAPACITY LOW-EARTH ORBIT APPLICATIONS IN FY'80

RECENT PROGRESS

- DESIGN OF TORROIDAL CELL, INVESTIGATION OF FABRICATION AND SEALING TECHNIQUES INITIATED BY LERC

Figure 1-5

POTENTIAL APPLICATIONS

- PRIMARY - PLANETARY PROBES
- SECONDARY - PLANETARY ORBITERS, LANDERS

OBJECTIVES

- DEMONSTRATE SAFE 300 WHR/KG PRIMARY PROBE BATTERIES WITH 5-YR STORAGE LIFE AT C/1 BY END OF FY'84
- DEMONSTRATE 220 WHR/KG SECONDARY LANDER BATTERIES BY END OF FY'82

RECENT PROGRESS (PROGRAM REORIENTED LAST QTR OF FY'79)

- LITHIUM ANODE CONDUCTING FILM MODELING INITIATED AT JPL
- $\text{LiAsF}_6$  SELECTED AS CANDIDATE ELECTROLYTE FOR STUDY IN SECONDARY CELLS

Figure 1-6

POTENTIAL APPLICATIONS

- GEOSYNCHRONOUS, PLANETARY ORBITERS

OBJECTIVE

- ESTABLISH FEASIBILITY OF 5-YR,  $>200$  WH/KG SECONDARY BATTERY BY EOFY'82

RECENT PROGRESS

- FEASIBILITY OF REVERSIBLY INTERCALATING UP TO 2 EQUIVALENTS OF  $\text{Na}^+$  IN  $\text{VS}_2$  AND  $\text{NiPS}_3$  AT  $130^\circ\text{C}$ . DEMONSTRATED BY LERC/EIC.

Figure 1-7

POTENTIAL APPLICATIONS

- GEOSYNCHRONOUS, LOW-EARTH ORBITERS

OBJECTIVES

- COMPLETE PRELIMINARY EVALUATION OF 77 WH/KG, 50 AH  $\text{Ag-H}_2$  CELLS IN FY'80
- COMPLETE PRELIMINARY EVALUATION OF  $\text{Ni-H}_2$  BATTERIES FOR HIGH-CAPACITY LOW-EARTH ORBIT APPLICATIONS IN FY'80

RECENT PROGRESS

- 50 AH, 80 WH/KG  $\text{Ag-H}_2$  CELL HAS COMPLETED 600 CYCLES AT LERC

Figure 1-8